STRONGLY COUPLED 3-D FINITE ELEMENT FORMULATION FOR MODELING MICRODEVICES WITH DOMINANT FRINGING FIELDS

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Increased functionality of the microelectromechanical systems (MEMS) has lead to the development of micro-scale devices that are geometrically complex. These complex configurations require the development of new and more efficient finite element (FE) techniques for modeling MEMS devices. This is due to the fact that lumped modeling and semi-analytical approaches are not applicable for the complicated geometries where fringing electrostatic fields are dominant. In this investigation, a novel strongly coupled 3-D tetrahedral transducer element is introduced for modeling the quasi-static behavior of analog electrostatic MEMS devices. This new transducer element, which can be utilized for a broad range of micro-system applications (i.e. combdrives and electrostatic motors), is compatible with conventional electrostatic and structural 3-D finite elements (FE). The element is capable of efficiently modeling interaction between deformable or rigid conductors that generate an electrostatic field. Strong coupling between the electrostatic and mechanical domains allows the static element formulation to be extended to transient and full harmonic analyses. Therefore, in many respects, the element is most sophisticated FEA tool available for modeling MEMS problems where dominant fringing fields develop.

The new element takes the form of a tetrahedral field FE with structural displacements and potentials as degrees of freedom. The element's potential energy is stored in the electrostatic domain and follows standard Ritz – Galerkin variational principles to ensure its compatibility with regular finite elements. The mechanical forces and electrical charges in the element are calculated using the virtual work principle. These element forces and charges are then used as entries for the vector of the Newton – Raphson restoring nodal forces. For the element, a modified tangent stiffness matrix is developed that consists of four components: structural tangent stiffness, tangent capacitance, and two symmetric coupled matrices. To increase accuracy and to ensure a robust convergence of the non-linear solution, the integrals and derivatives of the element's formulation are calculated analytically.

After the element formulation is presented, several benchmark problems are solved using the developed 3-D transducer element. The results of these problems are then compared to those obtained using standard traditional techniques and commercial software (such as ANSYS\Multiphysics). Based on the accuracy, convergence speed, and efficiency of the new element in the benchmark problems, it appears to be very attractive method for solving large transient problems found in the MEMS industry.